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A MINERALOGIC STUDY OF THE SASKATCHEWAN SANDS AND GRAVELS

S.A. ANTONIUK

1954

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A B S T R A C T

This thesis embodies the results of a study of the Saskatchewan Sands and Gravels with an attempt to determine their source. Mechanical analyses, insoluble residue tests, heavy mineral analyses and light mineral analyses of the sand portions were the methods of approach.

Mechanical analyses show a well sorted sand of medium to fine grain size. An absence of coarse sand was noted, even where the gravel phase was present. Clay and silt were found to be minor constituents except in basal samples where shales from the underlying bedrock increase the clay content of the sample.

Insoluble residue tests show an increase of soluble material as the mountains are approached. This suggests a source from the Rocky Mountains. Heavy mineral analyses revealed the presence of a metamorphic suite of minerals. Light mineral analyses showed angular quartz dominant with secondary amounts of carbonates and feldspar. The presence of angular grains, unstable minerals and a lack of weathering indicate a primary source to the west. Three possibilities for source areas arise:

(1) pre-existing Tertiary deposits of the plains

(2) Rocky Mountains east of the continental divide

(3) mountains west of the present divide composed in part of metamorphic rocks. Emphasis is placed on the last two sources. Streams depositing the Saskatchewan sands and gravels are believed to have originated in areas west of

the present divide and to have flowed through the Rocky Mountains onto the plains. Subsequent stream capture and uplift have resulted in the present continental divide.

The age of the Saskatchewan sands and gravels is uncertain. However, the lack of weathering suggests the time of deposition as one immediately preceding glaciation in the area.

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THE UNIVERSITY OF ALBERTA

A MINERALOGIC STUDY
OF THE
SASKATCHEWAN SANDS AND GRAVELS

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

FACULTY OF ARTS AND SCIENCE

DEPARTMENT OF GEOLOGY

by

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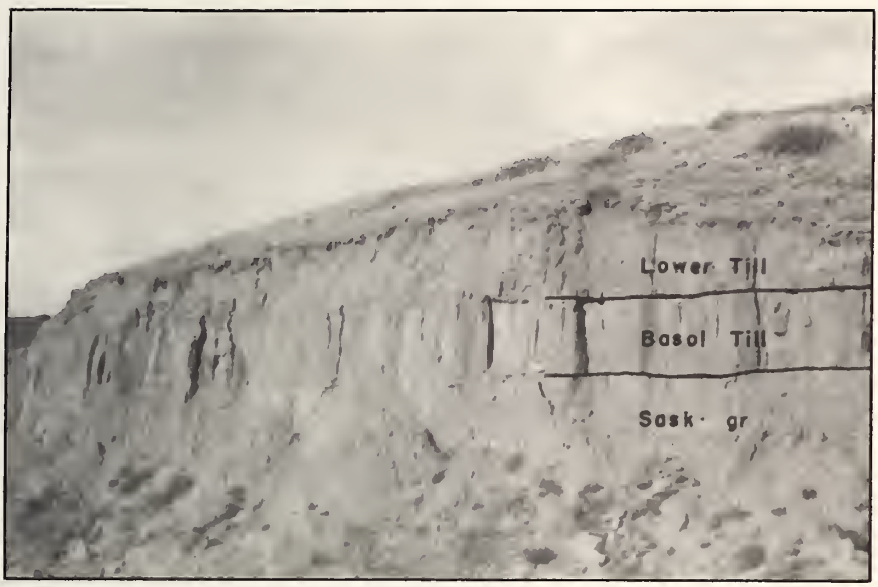
FRONTISPIECE

Section at Lethbridge, Alberta, showing the Saskatchewan gravels overlain by the distinctive Basal Till.


Lower Till
Basal Till
Sask. gr

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CHAPTER I

INTRODUCTION

General Statement

The presence of the Saskatchewan sands and gravels has been known since the start of geological investigation in Alberta. However, no detailed mineralogic study of the sands has been made. They have been mentioned by many geologists but generally their views are those of previous writers or are made on a basis of cursory field investigation. Thus the project was undertaken with an attempt to throw some new light on the size distribution and mineralogic content of the Saskatchewan sands and gravels. The results in turn may be used to provide evidence regarding their source and age.

The methods used were: size analyses, insoluble residue tests, heavy mineral analyses and light mineral analyses. Emphasis is placed on the heavy mineral analyses.

Acknowledgements:

The writer wishes to express his sincere appreciation to all members of the Department of Geology, University of Alberta, for their assistance and encouragement during the writer's graduate and undergraduate years.

Thanks are especially due to Dr. C.P. Gravenor under whose direction and guidance this thesis was

written and to Dr. P.S. Warren for aid in the location of sections.

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Previous Work:

The deposits concerned were first named the "South Saskatchewan Gravels" by R.G. McConnell (1885). He recognized their presence on the North Saskatchewan River and Missouri River branches but believed them to be most abundant in the South Saskatchewan River drainage system. Writers, however, soon dropped the term "South". R.L. Rutherford (1937), preferred the extended term "Saskatchewan Gravels and Sands" as in places of Central Alberta, sand is the dominant constituent. First reference to these beds in the Edmonton District was made by J.B. Tyrrell (1886).

Writers often referred to them merely as the "Quartzite gravels", even after the name "Saskatchewan Gravels" was assigned, because of the abundance of quartzite pebbles in the gravels. This has led to some confusion since writers also use the term "Quartzite gravels" for the Tertiary deposits covering the Cypress, Hand and Swan Hills.

Although much has been written about the Saskatchewan sands and gravels, their age and source are still disputed. McConnell (1885) originally sug-

gested that they were derived from late Tertiary conglomerates. Tyrrell (1890) called them Pliocene, having been derived in part from pre-existing Miocene deposits and in part directly from the quartzite areas of the mountains. Dawson (1895) concluded that the Saskatchewan gravels were, for the main part, of glacial origin and graded into a "western boulder clay" of a Cordilleran glaciation. Dawson thought this glaciation was antecedent to Kansan glaciation and suggested that this stage be named Albertan with the "Albertan formation" to comprise both the western boulder clay and the Saskatchewan gravels. He also recognized a lower set of gravels which antedated glaciation, thus concluding that the Saskatchewan gravels included both preglacial and glacial material. He thought no great chronological break was necessary between the two modes of deposition.

F.H. Calhoun (1906) rejected the idea saying they are of pre-glacial origin. He believed that they were derived from a higher Tertiary plain that had been raised tectonically. Alden and Stebinger (1913) were of the opinion that the Saskatchewan gravels are interglacial deposits formed from erosion of a pre-Wisconsin mountain drift. Alden (1932) later elaborated on this theory and drew up a correlation with a set of Pleistocene terraces in Montana. The gravel deposits on these terraces appear to be older than any Keewatin drift on the Montana

plains. Williams and Dyer (1930) believe that the deposits included under Saskatchewan gravels by McConnell vary in age of deposition from early Pliocene to early Pleistocene or even interglacial. They point out that in the river gravels described by McConnell and others, the rock is practically identical with that of the Cypress Hills formation and that whatever the final means or age of deposition most of the quartzite gravels belonged originally to the Cypress Hills conglomerate formation.

Rutherford (1937) said the Saskatchewan gravels and sands were preglacial in the sense that they antedate glaciation from the north and east and lie on bedrock. He was inclined to the view that the gold, which is found in the Saskatchewan sands, and the coarse gravels were derived from late Tertiary deposits of conglomerate. He also mentions the coarser phases of the Paskapoo as a possible contributor. Rutherford stresses the fact that the gravels are widespread and not altogether restricted to river valleys. The thicker arenaceous beds he thought, are confined to lower levels and the thicker gravel beds are more commonly found at higher elevations and somewhat removed from the lower parts of old drainage channels. L.S. Russell (1940) tentatively assigned the sands to the Pliocene since the absence of Laurentian pebbles favors a pre-glacial origin. Finally L. Horberg (1952) regarded the Saskatchewan gravels as pre-glacial

but states that it is uncertain whether they are early Pleistocene or late Tertiary in age or whether they are primary or reworked from older gravels.

Taylor (1934) mapped the deposits of the Edmonton area in detail and mentions several sections of Saskatchewan sands and gravels.

Work on pebble counts by Rutherford (1937) shows that the gravels are of two types, namely pieces of undecomposed bedrock of local derivation and pebbles or boulders derived from the west. In the Duff gravel pit, about 35 miles west of Edmonton, light coloured, smooth sandstones are dominant, with secondary amounts of chert and arkose pebbles. Fragments of the harder portions of the underlying bedrock are present at the base of the deposits. In the Lethbridge section, Horberg (1952) found quartzite dominant and argillites, dark and light coloured cherts, limestones, meta-conglomerate and shale present in minor amounts.

Duff (1951) carried out tests on sphericity and roundness of the Saskatchewan sands and gravels (sand portion). His results show the Saskatchewan sands to have a lower average sphericity (0.753) than any of the Pleistocene deposits in the area. His average sphericity for the Edmonton sandstone (0.80) was higher than that of the Saskatchewan sands which precludes any relationship between these two beds.

The occurrence of gold in the sand bars on the North Saskatchewan River has led to considerable discussion. Tyrrell (1915) said gold was first discovered in paying quantities in the North Saskatchewan River in 1860 or 1861 at Rocky Mountain House, by American prospectors. Tyrrell said that most of the gold came from the Edmonton formation on the basis of traces of gold found in ashes from burnt out coal of the Edmonton formation. A.R.C. Selwyn (1874) concluded that the original source of the gold was from Precambrian rocks of the glacial drift. Dawson (1884) supported Selwyn's views on origin. Rutherford (1937) stated that most and perhaps all the gold of the North Saskatchewan bars and terraces was derived from the arenaceous phases of the Saskatchewan gravels and sands. His work showed that in all cases the richer beds were present in low spots at the base of about 60 feet of sands in river cuts.

Field Work:

The field work was done in the fall of 1953. In order to obtain a wide picture of the mineralogic content, samples of Saskatchewan sands and gravels were collected from well distributed sections throughout southern and central Alberta. Samples of older Tertiary beds were picked or received from the Department of Geology collection for comparison purposes.

Samples were obtained from the following sections:

(1) LETHBRIDGE.

S10 - Section on the south-east bank of Oldman River along Highway No. 3, near bridge. (Twp. 9, Rge. 22, W. 4th).

(2) RED DEER.

S7 - Section on north bank of the Red Deer River, west of the Red Deer Golf Course. (Twp. 38, Rge. 27, W. 4th).

(3) LAKE WABAMUN.

S2 - Section from the abandoned Blue Flame strip mine on the north side of Lake Wabamun. (Twp. 53, Rge. 4, W. 5th)

S3 - Section from the Victory strip mine on the north shore of Lake Wabamun. This section is a few miles west of the Blue Flame strip mine. (Twp. 53, Rge. 4, W. 5th).

(4) EDMONTON AREA.

S12 - Big Bend section on the north bank of the North Saskatchewan River; west of the Country Club Golf Course. (Sec. 14, Twp. 52, Rge. 25, W. 4th).

S13 - Groat Ravine section; within the City limits of Edmonton, immediately below the bridge crossing Groat Ravine at 102 Ave. and 125 St. (Twp. 53, Rge. 24, W. 4th).

S5 - Section on the south bank of the North Saskatchewan River within the Edmonton City limits; below the University of Alberta staff residences. (Twp. 52, Rge. 24, W. 4th).

(5) PEMBINA RIVER.

P1 - Sample of the basal member of the Paskapoo formation as exposed on the east bank of the Pembina River; just above Highway No. 16 crossing. (Twp. 53, Rge. 7, W. 5th)

(6) HAND HILLS.

H1 - Sample of the Hand Hills conglomerate obtained from the Dept. of Geology, University of Alberta collection. Originally collected by J.O.G. Sanderson from outcrop in the Hand Hills. (Twp. 29, Rge. 17, W. 4th).

Where more than one sample was collected from a section, the samples were lettered from the top down in alphabetical order. Samples were collected at 10 foot intervals except where a change was noted and in such cases, the sample was collected from the bed showing the change in lithology. (see Appendix)

The sections of the Saskatchewan sands and gravels were found to be underlain by Cretaceous beds. The relief on these Cretaceous beds was sufficient in some instances to make the Saskatchewan sands and gravels very thin or absent. This relief probably represents banks of the old streams within which the sands and gravels were deposited (see Plates 1 and 2). The top of the Saskatchewan sands and gravels was found to be relatively level. Some crushing of the pebbles in the uppermost part was noted at Lethbridge and Lake Wabamun. This crushing was probably due to the work of the glaciers. However, at Lake Wabamun heavy machines stripping off the overburden to get to the coal may have caused the crushing.

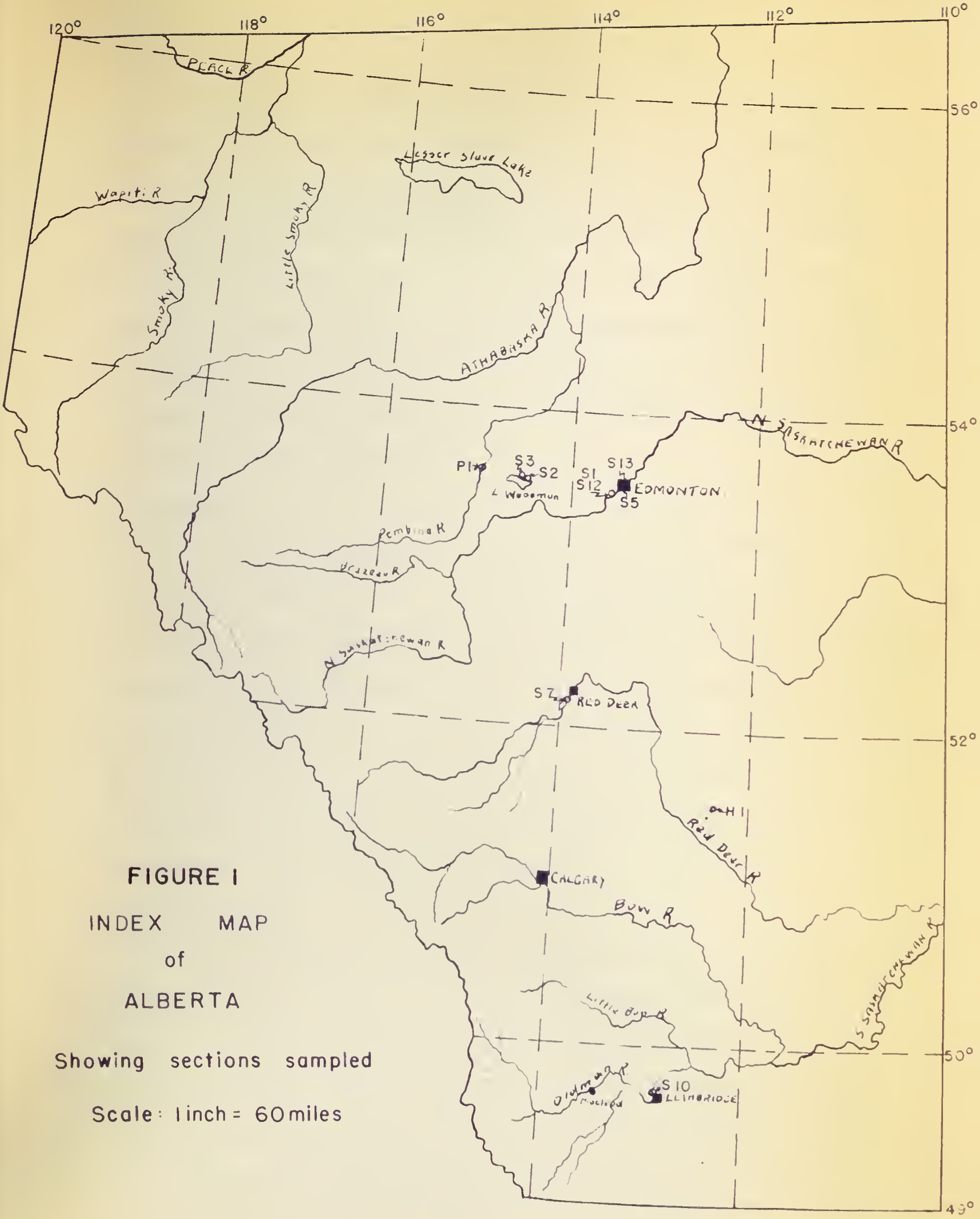


FIGURE I

INDEX MAP of ALBERTA

Showing sections sampled

Scale: 1 inch = 60 miles

CHAPTER II

MECHANICAL ANALYSES

Mechanical analyses were made of all the samples collected. The results were plotted on histograms and cumulative curves. Where present, the gravel content was omitted and only the sand portion was analysed since an analysis of the gravel would have required the use of unusually large samples to be representative. Also, an analysis of the gravels would have required a measuring of each individual pebble and the results probably would not warrant the time taken.

Procedure:

A preliminary screening with a 2 mm. (10 mesh) screen was carried out to eliminate the gravel portion. A 150 gram sand sample was then placed in a "milk shake" disperser and dispersed for a period of ten minutes in a 1:40 solution of sodium hexametaphosphate. This proved to be an important step, as it aided in the removal of a silt and clay lag from the screens which would give both inaccurate weighings and contamination on the heavy mineral slides.

A wet screening of the dispersed sample was then carried out through a 0.062 mm. (230 mesh) screen (the sand-silt break). The coarser material was dried and weighed to find loss in weight. The fine material was washed into a settling cylinder (one litre volume) and a size analysis of this material was carried out on the basis of Stoke's Law of settling of fine particles. The

Wentworth scale was used for the breaks in the silt and clay. At the end of the prescribed settling time a sample was taken at a 10 cm. depth by means of a pipette. This sample was then dried and weighed. Calculation of the portion was carried out to find the weight percentage of the total. Breaks were made for particle diameters of 0.0313, 0.0156, 0.0078 and 0.0039 mm. The 0.0039 mm. (3.9 micron) break was used as the silt-clay break. An analysis of the clays was not attempted, rather the total clay content was placed in one group. (See histograms).

The dried sand portion was screened for a 15 minute period on a Cenco-Meinzer Sieve Shaker using 8 inch U.S. Standard Sieves of the following dimensions:

U.S. Sieve Series Mesh No.	Screen Openings in Mm.
10	2.00
14	1.41
18	1.00
25	0.707
35	0.500
45	0.354
60	0.250
80	0.177
120	0.125
170	0.088
230	0.062

The weight percentages of the sand on each screen were calculated and plotted in the form of histograms. Cumulative weight percentages were also plotted giving cumulative curves. In the dry screening, a residual silt, finer than the 230 mesh appeared on the pan. This was added to the coarse silt obtained by the

settling process since a test showed that this material settled below the first silt break used in the settling process.

Tables of the actual weight percentages are not printed as the results are evident on the histograms.

Histograms:

The histograms are plotted using the Wentworth Scale as the abscissa and the weight percentages as the ordinate. The values in the sand portions are represented as shaded bars. The silt breaks are twice as large as the sand breaks and are cross-hatched. The last cross-hatched bar on each histogram shows the total clay content of the samples.

It is stressed that the grade scale used on the abscissa of histograms should be carefully observed as different grade scales give different histogram shapes. A fine scale, with small diameter ranges is desirable since a better location of the "maximum" will be shown. However, in such a case the peakedness of the histogram will appear less pronounced.

Cumulative Curves:

Graphs are drawn up for each sample to show the cumulative weight percentages in going from coarse to fine material. The Wentworth Scale is plotted along the abscissa and the cumulative weight percentages along the ordinate axis, thus at any point on the graph the ordinate reading gives the weight percentage of all the

material coarser than the size represented.

The median size (50%) and the two quartile sizes (25% and 75%) were read from the cumulative curves (see Table 1) and the coefficient of sorting was obtained for all the samples using the following equation:

$$\text{Coeff. of sorting (So)} = Q3/Q1$$

where $Q3 = 25\%$ quartile
$Q1 = 75\%$ quartile

Skewness was calculated using the following equation:

$$\text{Skewness (Sk.)} = \frac{Q1 \times Q3}{Md^2}$$

Skewness indicates on which side of the median diameter, and how far from it, the mode or peak of size distribution lies. As a positive logarithm of skewness indicates a mode on the fine side of the median, and a negative logarithm on the coarse side, it is convenient to use the logarithmic values rather than the values obtained from the above formula.

An attempt at finding the kurtosis (peakedness) of each sample was made, however the values obtained were erratic and proved useless. Perhaps the reason for this is that the percentiles (10 and 90% cumulative points) which are used in the formula may be affected by the tails of the graph. These are the extremities of the curve which do not appear to conform to the same laws as the body of the sample. (See Doeglas, D.J. (1946)).

Interpretations:

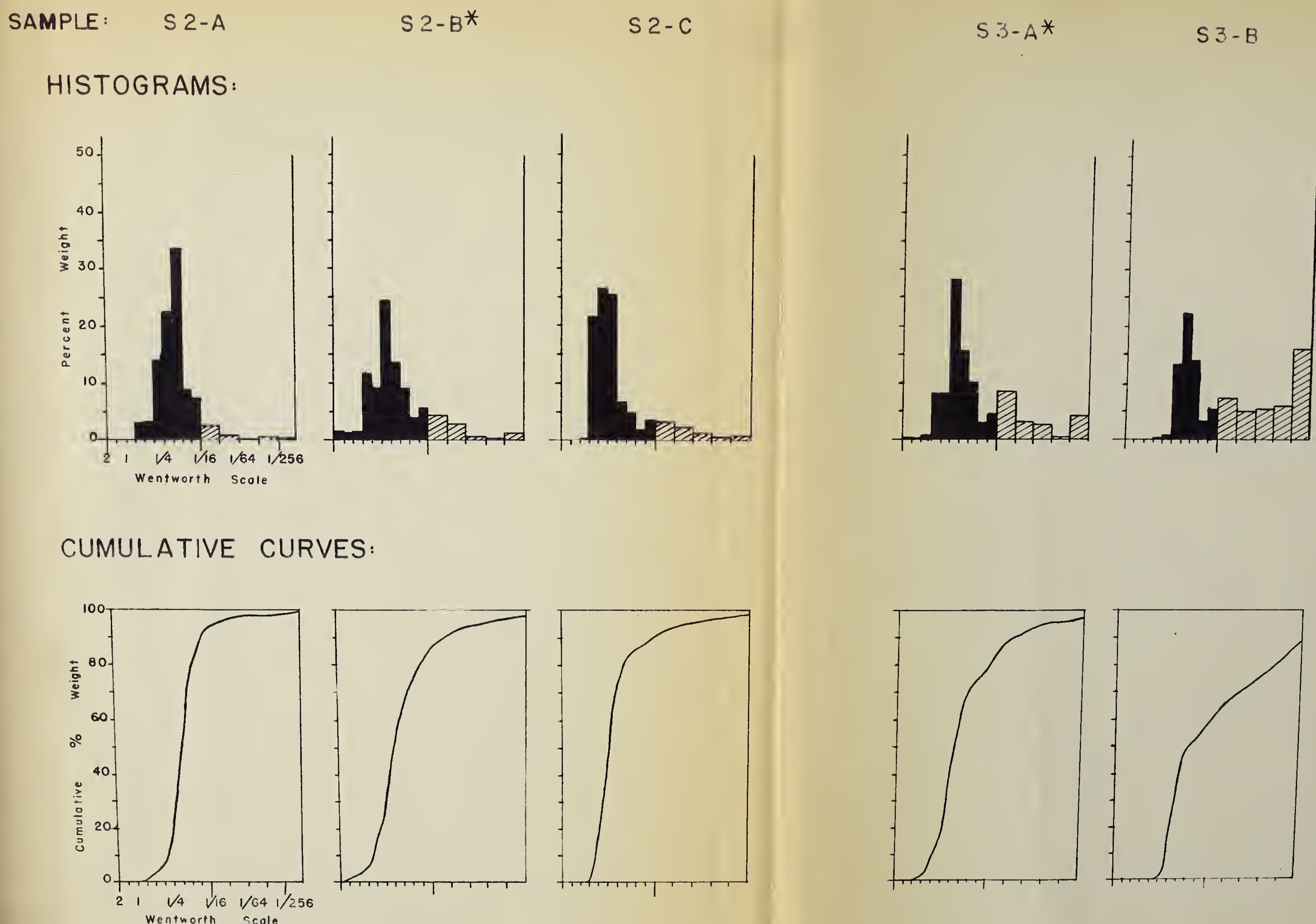
A study of the histograms adequately shows many

TABLE 1.

SIZE ANALYSES VALUES.

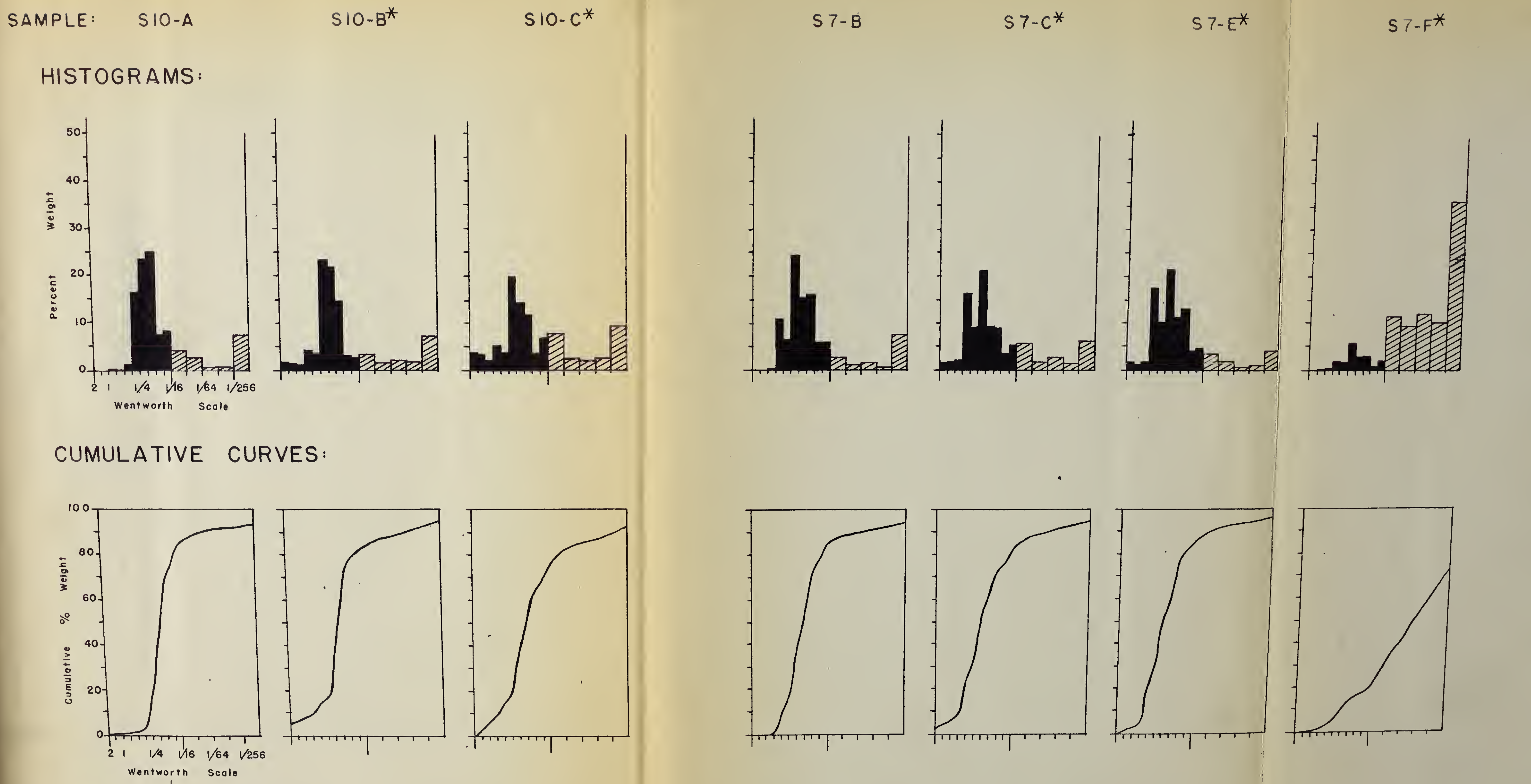
Sample	Md.	Q3	Q1	Coeff. of Sorting	Median Sand Size	Sk.	Log_{10}Sk.
S2-A	0.17	0.23	0.14	1.28	Fine Sand	1.11	+0.045
S2-B	0.26	0.38	0.13	1.71	Med. " "	0.73	-0.137
S2-C	0.34	0.45	0.23	1.40	" " "	0.89	-0.050
S3-A	0.22	0.31	0.09	1.85	Fine Sand	0.58	-0.240
S3-B	0.13	0.20	0.008	5.00	" " "	0.95	-0.024
S7-B	0.22	0.32	0.12	1.63	Fine Sand	0.79	-0.101
S7-C	0.27	0.50	0.10	2.24	" " "	0.69	-0.164
S7-E	0.26	0.45	0.14	1.79	" " "	0.93	-0.031
S7-F	0.01	0.05	0.003	3.73	-	1.50	+0.176
S10-A	0.16	0.21	0.09	1.53	Fine Sand	0.74	-0.132
S10-B	0.21	0.31	0.13	1.54	" " "	0.92	-0.038
S10-C	0.19	0.31	0.06	2.27	" " "	0.52	-.287
S12-A	0.22	0.28	0.16	1.32	Fine Sand	0.93	-0.033
S12-B	0.12	0.17	0.08	1.46	Vy. Fine Sand	0.95	-0.025
S12-C	0.31	0.37	0.26	1.19	Med. Sand	1.00	0
S12-D	0.22	0.29	0.16	1.35	Fine Sand	0.96	-0.018
S12-E	0.22	0.30	0.15	1.41	" " "	0.93	-0.013
S12-F	0.18	0.26	0.12	1.47	" " "	0.96	-0.016
S12-G	0.28	0.32	0.19	1.30	Med. Sand	0.78	-0.111
S12-H	0.28	0.34	0.21	1.27	" " "	0.91	-0.040
S12-J	0.25	0.31	0.18	1.31	Fine Sand	0.89	-0.049
S12-K	0.26	0.36	0.16	1.50	Med. Sand	0.85	-0.070
S13-A	0.19	0.26	0.15	1.41	Fine Sand	0.94	-0.028
S13-B	0.20	0.29	0.13	1.49	" " "	0.94	-0.026
S13-C	0.15	0.22	0.08	1.66	" " "	0.78	-0.107
S13-D	0.16	0.21	0.13	1.27	" " "	1.07	+0.028
S13-E	0.21	0.29	0.15	1.39	" " "	0.99	-0.005
S13-F	0.18	0.24	0.13	1.36	" " "	0.96	-0.017

FIGURE 2



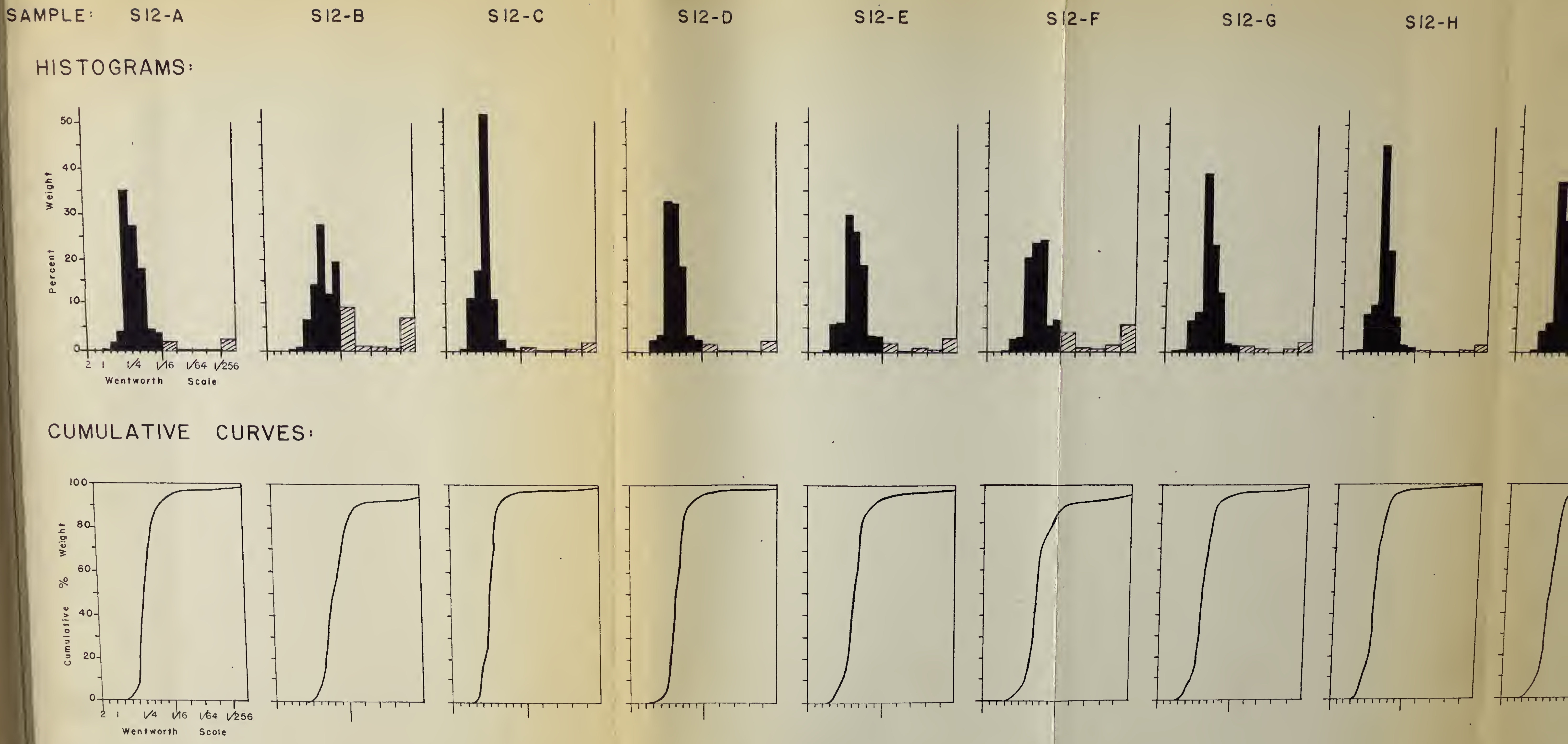
*Denotes sand portion of sand-gravel mixture

FIGURE 3



*Denotes sand portion of sand-gravel mixture

FIGURE 4



*Denotes sand portion of sand-gravel mixture

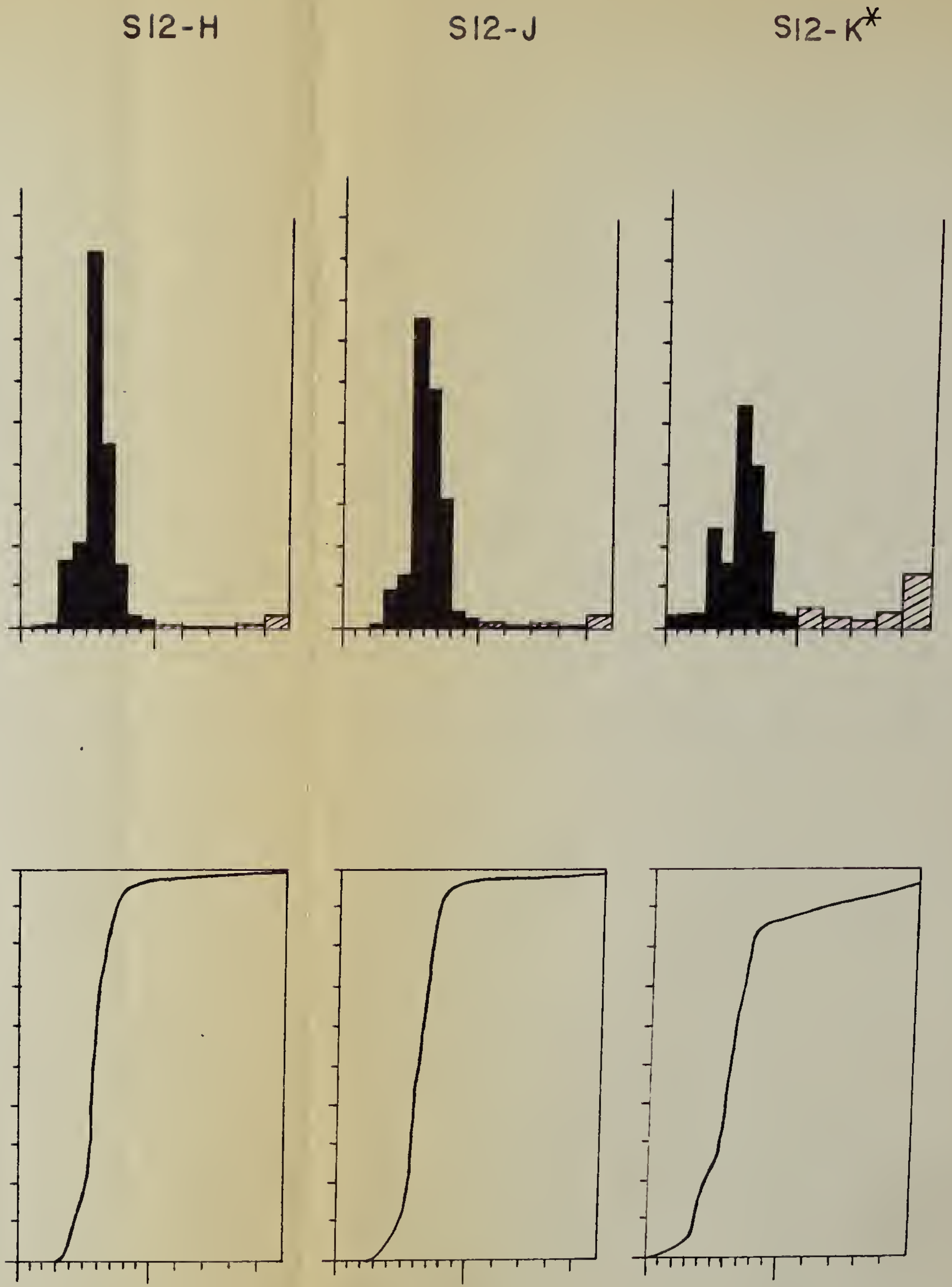
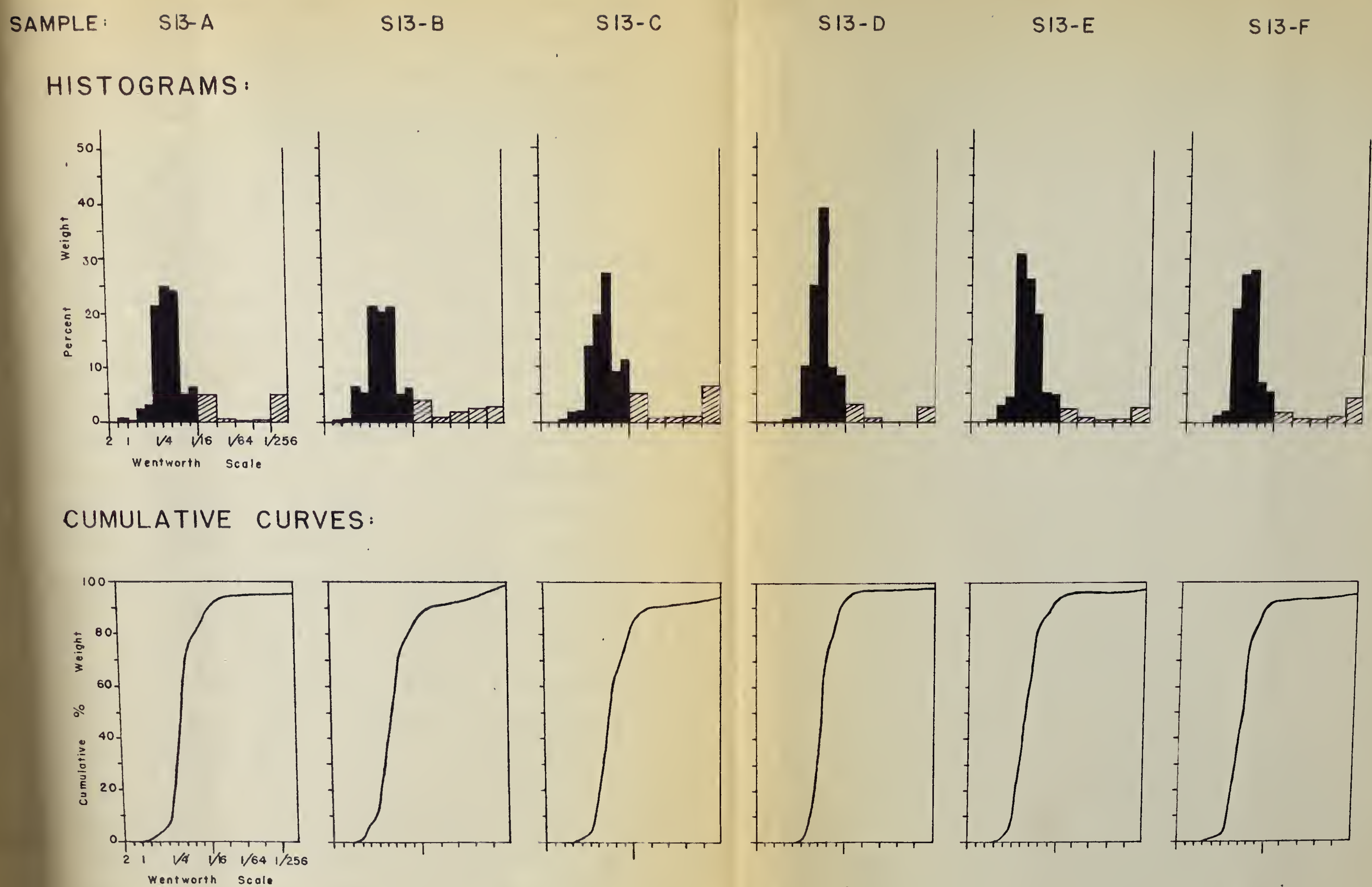

S12-H
S12-J
S12-K*

FIGURE 5


SAMPLE:
S13-A
S13-B
S13-C
S13-D
S13-E
S13-F
HISTOGRAMS:
Percent Weight
50
40
30
20
10
0
2
1
1/4
1/16
1/64
1/256
Wentworth Scale
CUMULATIVE CURVES:
Cumulative % Weight
100
80
60
40
20
0
2
1
1/4
1/16
1/64
1/256
Wentworth Scale

features, eg., dominant grain size, degree of sorting, presence of secondary modes, and skewness of the sample. Numerical values obtained from the cumulative curves, while of interest, generally proved less diagnostic than the histograms. Perhaps a widening of the spacing along the abscissa would result in the cumulative curves showing features not observed in the curves plotted.

The results show that medium to fine sand is the dominant portion of the samples. In some cases clay predominates over silt in the fine fraction, but generally clay and silt are present in approximately equal amounts. The predominance of clay over silt was found to be present in basal samples where shale from the underlying bedrock forms a large part of the sample. It is to be noted that in practically all cases very coarse and coarse sand is scarce. The absence of coarse sand proves especially interesting since gravel is often present. Is this an indication that the coarse sand size is relatively unstable or that two sources for the material are present?

Gravels consist almost exclusively of rock fragments. The fine sand on the other hand is dominantly single grains, i.e., the fragments are crystallographic units. Perhaps crystal grains of the very coarse sand size are rare. Also, rock fragments of the very coarse sand size present a greater surface per volume of fragment, allowing for a fast effective weathering of the cementing agent so that this size would be quickly broken down.

On the other hand, the absence of material between gravel and medium sand may indicate two sources for the material. The gravels may have been derived locally from pre-existing Tertiary conglomerates and the sand portion may have been derived from the mountains to the west. Thus the metamorphic rocks, sandstones and quartzites of the mountains may have been broken down to monomineralic sizes. However, a similar condition for material analysed by other men is to be noted. (Pettijohn 1949, p. 41)).

Bimodal distribution of the sand was found to be scarce except in the Red Deer section. The significance of this is not understood. Note, however, that here one horizon (S7-D) was a gravel bed with no interstitial sand whatsoever. Perhaps there is a relation between these two anomalies.

The coefficient of sorting indicates good sorting in the majority of the samples, generally being somewhat less in sand from sand-gravel mixtures. Trask (see Pettijohn (1949, p. 24)) says a coefficient of sorting less than 2.5 indicates a well-sorted sediment and a value of 3.0 is average. Hough (1940) and Stetson (quoted by Hough), on the basis of near-shore marine sediments, say that 1.45 is the average coefficient of sorting. Krumbein and Tisdel (1940) found coefficient of sorting values between 1.96 and 1.28 for granite and gneisses weathered in place. However, they hint that the above samples all

have a positive log skewness whereas most transported sediments show a negative log skewness, as is the case of the Saskatchewan sands.

Twenhofel (1941) says that the best that a graph can do is suggest an environment of deposition and an agent of deposition. On the whole the statistical results obtained for the Saskatchewan sands should be used with caution and little can be done with them alone. However, they may be more significant when used in conjunction with mineral analyses.

CHAPTER III

MINERALOGIC ANALYSES

1. INSOLUBLE RESIDUE TESTS

Insoluble residue tests were carried out to determine the amount of carbonate found in the sand fractions. The results are shown in Table 2 and are given in percentage of soluble material rather than insoluble residue as the smaller percentage values for the soluble materials give a better comparison.

25 grams of each sample was treated with 3N. HCl for a period of 12-15 hours.

Interpretations:

The results shown in Table 2 indicate that those samples taken nearest the mountains have the highest amount of carbonate. Microscopic studies of the light mineral fraction indicate that the carbonate occurs as primary fragments. The Lethbridge section, which is the section taken nearest the mountains (approximately 65 miles), has the highest soluble material content; the Red Deer section, which was taken about 90 miles from the mountains, ranks second in the abundance of soluble material; the Lake Wabamun and Edmonton sections (125 and 160 miles distant respectively) are lowest in soluble material content. Exceptions to the above general trend are first, basal samples where bedrock material affects the results considerably (see S7-F) and secondly, secondary carbonate-rich horizons. The latter were recognized in

the field as better indurated sand beds and the carbonate was present as a cement rather than carbonate grains. (see S13-B).

TABLE 2.

INSOLUBLE RESIDUE TESTS.

Section	Sample	% Solubles
Lethbridge	S10-A	11.7
	S10-B	14.3
	S10-C	11.8
Red Deer	S7-B	4.0
	S7-C	8.4
	S7-D	--
	S7-E	9.8
	S7-F	17.2
Lake Wabamun	S2-A	3.3
	S2-B	9.2
	S2-C	5.9
	S3-A	1.8
	S3-B	6.5
Edmonton (Big Bend)	S12-A	5.8
	S12-B	4.0
	S12-C	2.2
	S12-D	3.2
	S12-E	2.9
	S12-F	3.7
	S12-G	2.5
	S12-H	2.0
	S12-J	2.6
	S12-K	4.6
(Groat Ravine)	S13-A	2.9
	S13-B	14.3
	S13-C	5.1
	S13-D	3.1
	S13-E	1.9
	S13-F	2.3

2. HEAVY MINERAL ANALYSES.

Emphasis is placed on heavy mineral analyses as they are considered a useful sedimentation method for the determination of source beds, cycle of deposition and degree of weathering. The results of the analyses for the different sections are placed on separate tables and a table showing the average for each section has been prepared for comparative purposes.

Mineral Separation Procedure:

The sand portion between the 120 and 230 mesh sizes, obtained from the mechanical analyses, was used for this analysis. The heavy mineral fraction was separated from the light fraction using tetrabromoethane (Sp. Gr. 2.965) in separatory funnels. Air, which is dissolved in tetrabromoethane, alters the specific gravity of that material and collects around the grains thereby affecting the settling. Therefore, in order to obtain a complete recovery, the dissolved air was removed by the use of a vacuum pump.

After separation was complete, the heavy minerals were funnelled off, washed with acetone and dried. The heavy minerals were then mounted on slides in a medium of aroclor, ($n = 1.66$). This medium is better than Canada balsam as the refractive index is nearer the average index of the heavy minerals. It is found that the heavy minerals are divided into two approximately equal groups on the basis of greater or lesser index than the medium. Further, aroclor does not require cooking, hence is

easier to work with than Canada balsam.

Many of the mineral grains had a clouded appearance and several methods were used in an attempt to clear them. Boiling of the heavy minerals in water was attempted but the attempt proved unsuccessful. Where abundant, ferric oxide coating was removed by boiling in dilute HCl. This method proved successful but a loss of apatite doubtless occurred.

The amount of heavy minerals recovered ranged from 1 to 5% with an average of about 2.5% of the total sand fraction within the size range used for separation. On each slide, 350 to 400 mineral grains were counted and the percentage of each mineral recorded (see tables 3, 4, 5, 6). Identification was made using a Leitz petrographic microscope with a mechanical stage.

Mineral Descriptions:

Garnet: As it is difficult to differentiate spinel from garnet, it is possible that small amounts of spinel were counted in with the garnet, however, it is doubtful that this would seriously affect the overall garnet count. Garnet is the most common of the transparent minerals, forming an average of 14% of the total minerals counted.

A colorless variety is by far the most common type found except in the Lethbridge section where a yellow-brown to brown variety makes up over 60% of the total garnets. A few pink garnets were noted in most slides. Although a few of the colorless to pink varieties

showed crystal form, most are angular grains showing a conchoidal fracture (see Plate IV). Inclusions are not common though they are present in some grains; little straining is evident. Except for color the pink variety appears very similar to the colorless varieties. The yellow-brown variety consists of angular grains but the conchoidal fracture is less evident and the refractive index is lower than for the colorless variety.

Incipient alteration of the garnets appears to have taken place as is shown by the pitting of some grains (see Plate IV). Much argument has taken place on the stability of garnet but agreement has not been definitely reached. Latest indications are that garnet is relatively stable with the exception of iron rich varieties which are somewhat less stable. (Allen, V.T. (1948)).

Epidote: This mineral forms about 10% of the total mineral assemblage. Three varieties of epidote are found; first, clear somewhat rounded grains, second, dusky grains showing clear edges, and third, nearly opaque grains showing translucent yellow-green edges. A good determination of the third variety was not possible and these were placed under altered minerals where a reference to them will be made.

The diagnostic properties include a yellowish green color with pleochroism from yellow-green to colorless or light yellow-green. The dusky grains show a darker

yellow-green and less pleochroism. Birefringence is high indicating an Fe rich epidote; fair dispersion was noted. A distinguishing feature of many grains was an optic-axis figure giving a one-bar (compass-needle) interference figure with a negative sign.

The gradtation into dusky and opaque grains with clear edges probably indicates an incomplete alteration to epidote during metamorphism. Winchell and Winchell (1951, p. 450) say alteration of epidote due to weathering is rare.

Hornblende: This mineral is present in all samples but never very abundant. About 3% of the total heavy mineral suite was found to be hornblende, except in the Lake Wabamun samples where the amount rose to 6-7%. Common hornblende is the dominant type though tremolite and actinolite were recognized as traces. Hornblende was recognized by its distinct cleavage, small extinction angle and pleochroism. Various shades of green are dominant with pleochroism as follows; green to olive green, green to greenish-brown, green to forest green, and yellow-green to bluish-green.

An interesting occurrence was found in the sample of Paskapoo sanstone (9% hornblende). Here the variety appears very similar, however, the ends of many of the grains are jagged and lack any evidence of rounding (see Plate IV). Inclusions are common and alteration is noticeable on many grains, often as holes in the grains or

as altered material along cleavage cracks (see Plates IV and V).

Titanite: Titanite forms about 2-3% of the total mineral assemblage. The grains are angular, often subhedral to euhedral (diamond-shaped), usually showing a light yellowish-brown color. Titanite is characterized by its high refractive index, high birefringence, very strong dispersion (blue in extinction position) and usually a distinct, well-centred interference figure. No alteration of the grains is present.

Zircon: Though never a common mineral in the slides, zircon is always present. It usually appears as colorless, unworn euhedral or subhedral crystals (see Plate VI). Inclusions are common, though seldom orientated. Zircon is recognized by crystal form, parallel extinction, high refractive index and high birefringence. Occasionally an off-centred, positive uniaxial figure was seen.

Tourmaline: Tourmaline forms about 1% of the total heavy mineral suite. The grains are angular and occasionally inclusions are present. Tourmaline is recognized by a refractive index just below 1.66 (usually), parallel extinction, elongate form and strong pleochroism as follow, yellow to brown or pink to deep green. Tourmaline is considered a stable mineral and an absence of rounding or alteration is noted.

Rutile: About 2% of the heavy mineral count is represented by rutile. The usual color types are a deep

rust brown and a dark blood red, though a deep yellow variety was occasionally noted. The diagnostic properties of rutile include its color, grains usually elongated, parallel extinction, very high birefringence and a very high refractive index giving a wide black border on the grain.

Staurolite: This mineral makes up about 2% of the total heavy mineral suite. Staurolite is recognized by its yellow color, hackly fracture, abundance of inclusions often giving a porous character to the grains, weak pleochroism, low birefringence and an optic axis figure showing a high 2V and negative sign.

Apatite: Usually apatite forms about 2.5% of the total heavy minerals counted but was rare in acid treated samples. It usually appears as somewhat rounded prismatic to egg shaped grains in which inclusions are common and usually parallel to the vertical axis of the crystal. However, radiating inclusions were also seen. (see Plate VI).

The diagnostic properties of apatite are a refractive index less than medium, colorless to dull white grains, parallel extinction, very low birefringence (a blue-grey color) and a negative uniaxial figure. A clouding of some apatite grains suggests alteration.

Topaz: Topaz is not common, forming less than 1% of the total heavy mineral suite. It appears as colorless grains and often is much like quartz except for somewhat lower relief. Topaz is determined on the basis of

refractive index lower than the medium, irregular fracture, one cleavage (not always clear), bright first order yellow and green interference colors, dispersion and an occasional positive biaxial figure. No alteration of the grains was noticed. Topaz is somewhat similar to andalusite but the latter is usually clouded, biaxial negative and shows less relief.

Chlorite: Between 1.5 and 2% of the total heavy mineral assemblage was found to be chlorite. It lacks greater abundance because of its variable specific gravity, from 2.6 to 3.0. Thus numerous grains remain with the light mineral fraction. The dominant color is green, also brown and yellow-green grains were seen. Chlorite is identified on the basis of its low birefringence and strong dispersion giving a wavy dull blue extinction and by its dusky interference figure having a small 2V.

A gradation of chlorite to almost opaque grains was noted, perhaps due to incomplete alteration, thus some chlorite may have been put under altered minerals. Milner (1929, p. 156) says definite identification as a detrital mineral is doubtful and suggests an original occurrence of ferromagnesian minerals such as augite, hornblende and biotite.

Chloritoid: This mineral is rare, forming less than 1% of the heavy mineral suite. It is distinguished by its pale blue color with slight pleochroism within the blues, weak birefringence, strong dispersion, re-

fractive index greater than 1.66, and platy habit. Dark inclusions, often with a radiating pattern, are very common in chloritoid (see Plate V). Alteration of the grains is evident, occasionally as holes in the grains.

Monazite: Monazite forms about 1% of the total heavy mineral assemblage. It has a similar appearance to titanite but its weaker dispersion, lower birefringence, yellow color and a biaxial figure which shows fewer color rings are usually sufficient to separate these two minerals. No alteration of the grains is noted.

Zoisite: Zoisite forms about 1% of the total heavy mineral suite. It is recognized by its low birefringence, abnormal ultra-blue interference colors, strong dispersion giving incomplete parallel extinction and a refractive index greater than 1.66.

Alteration of colorless zoisite is noted as cracked and dusky grains. Included under zoisite is clinozoisite which is very similar except for inclined extinction.

Biotite: Biotite is variable in abundance, completely lacking in some samples and forming up to 5% in others. It occurs as green and brown grains and is identified by its platy habit, refractive index less than aroclor, high birefringence and a good negative biaxial figure with a small 2V. Alteration of biotite is common with the grains often appearing cracked and bleached or containing holes. The variable abundance may be due to

differences in depositional conditions since its platy nature makes it very susceptible to stream current change.

Kyanite: Kyanite is a rare mineral in most sections and absent in the Lethbridge samples. When present the grains are angular (see Plate V). Kyanite is determined by its weak but distinct pleochroism of colorless to light blue, by good cleavage lines nearly at right angles (see Plate V), by low birefringence and inclined extinction. Alteration is present along cleavage cracks. Krumbein and Pettijohn (1938, p. 436) say rounded kyanite denotes a low current velocity and angular kyanite a high velocity.

OTHERS:

Pyroxenes were found in a few samples, usually considerably altered so that identification was not certain.

Andalusite was occasionally found in the samples as somewhat altered grains, giving a greyish color. Winchell and Winchell (1951, p. 522) say andalusite alters rather easily to sericite.

Corundum. Traces of corundum were found in about half the samples. It appears as clear grains showing a high refractive index and low birefringence. No alteration was noted.

Cassiterite was found in several samples. It is determined on the basis of euhedral habit, yellowish color

and high birefringence. Birefringence is somewhat less than for rutile, also the color is lighter.

OPAQUES:

Not much emphasis should be placed on the opaques since identification by reflected light is often haphazard. However a count of the opaques was included for the sake of constituting a representative sample.

Magnetite: This mineral constitutes 20-25% of the total heavy mineral assemblage. Ilmenite, if present, is included under magnetite since it is difficult to distinguish the two minerals. Magnetite was determined on the basis of metallic lustre, bluish-black to purplish-black color and the presence of octahedral facets due to crystal outline. Tests with a magnet revealed a high percentage of a magnetic mineral.

Hematite: Variable quantities of hematite were present but on the average it forms 5-6% of the total heavy mineral suite. Hematite lacks any structure, appearing as an earthy mass. It is distinguished by its brick red color and earthy appearance.

Hematite is probably a secondary mineral, often present as a partial coating on other grains. Because of its secondary nature and masking effect an attempt was made to remove it from the heavy minerals by the use of HCl.

Limonite: This mineral forms about 6% of the total

heavy mineral suite. It is an amorphous, earthy mineral of a yellow to yellow-brown color. Limonite is also a secondary mineral.

Leucoxene: About 3.5 to 4% of the total heavy mineral count consists of leucoxene, except in the Red Deer section where it rises to an average of 12.5%. Leucoxene is recognized by its rounded form, dull white color and pitted appearance. Milner (1929, pp. 197, 205) believes that it is formed in place from ilmenite.

Gold: Only two flakes of gold were found in the samples studied, one from the sample of Paskapoo and the other in a sample of Saskatchewan sands from Lake Wabamun. A slide was made of the gold obtained from the panning of a Saskatchewan sand concentrate from the Big Bend section, Edmonton area, (Dept. of Geology, University of Alberta, sample). The gold flakes are an average of 0.2 mm. in diameter. They are a mellow yellow color and have a pounded to sheared appearance.

Altered: This group, usually averages from 10-15% of the total count and gave considerable trouble in the mineral identifications. It was decided to include these minerals in the actual count since a few distinct types were present.

Approximately one-third of the altered minerals are believed to be epidote grains which are opaque due to incomplete alteration. The edges of these grains are translucent showing a yellow-green color and exhibiting interference colors of the correct order for epidote.

Opaque grains showing a light yellow color under reflected light and having a fibrous habit formed about 50% of the altered group. Occasionally, quartz grains with a limonite coating were recognized, these however where not included in the mineral count. There is a possibility that completely covered quartz grains may have been counted under limonite or altered grains.

TABLE 3.

HEAVY MINERALS OF LAKE WABAMUN SECTION

Sample No: Mineral	S2-A	S2-B	S2-C	Av.	S3-A	S3-B	Av.
Garnet	15.8	13.4	8.3	12.5	10.6	13.6	12.2
Epidote	12.0	6.3	4.5	7.6	8.3	2.2	5.3
Hornblende	5.6	1.9	1.3	2.9	9.4	1.1	5.3
Titanite	0.6	1.1	0.8	0.8	2.3	3.3	2.8
Zircon	T	2.5	1.3	1.4	0.9	1.7	1.3
Tourmaline	1.2	1.1	0.3	0.9	0.6	0.6	0.6
Rutile	1.8	1.9	2.2	2.0	2.0	2.5	2.3
Staurolite	5.3	0.8	1.8	2.6	4.0	1.1	2.6
Apatite	2.9	2.2	1.3	2.1	3.1	2.5	2.8
Topaz	T	0.6	0.8	0.6	0.9		0.5
Chlorite	1.5	1.9	1.5	1.6	1.2	1.7	1.5
Chloritoid	1.2			0.4	1.7	T	1.0
Monazite	1.2	0.8		0.7	1.7	1.4	1.6
Zoisite	2.3	0.8	0.8	1.4	1.4	0.6	1.0
Biotite	0.6	1.1	1.0	0.9	1.1	7.0	4.0
Kyanite	1.2			0.4	T	T	T
Others	0.6	1.1	0.5	0.7			
Unidentified	4.1	1.4	1.5	2.3	2.6	1.7	2.2
OPAQUES							
Magnetite	7.3	21.2	50.7	26.4	21.1	27.8	24.5
Hematite	2.9	8.7	3.0	4.9	3.1	9.2	6.2
Limonite	3.8	4.9	11.0	6.6	7.7	5.6	6.7
Leucoxene	4.1	4.6	3.0	3.9	1.7	2.5	2.1
Altered	18.1	11.4	4.8	11.4	14.6	16.1	15.4

T - means trace; other values are percentages.

TABLE 4.

HEAVY MINERALS OF LETHBRIDGE AND RED DEER SECTIONS

Sample No;	S7-B	S7-C	S7-E	S7-F	Av.	S10-A	S10-B	S10-C	Av.
Mineral									
Garnet	17.7	13.9	10.7	13.7	14.0	3.6	4.5	6.8	5.0
Epidote	10.2	5.7	4.4	10.2	7.6	3.3	5.2	4.9	3.8
Hornblende	2.8	3.2	2.5	2.9	2.9	2.1	4.8	3.3	3.4
Titanite	1.5	1.6	T	1.0	1.1	0.9	0.6	0.5	0.7
Zircon	T	1.3	1.4	1.6	1.2	T	1.3	1.9	1.2
Tourmaline	1.2	1.3	0.5	1.0	1.0	0.6	1.3	1.4	1.1
Rutile	1.9	3.2	1.4	1.9	2.1	T	T	1.4	0.7
Staurolite	1.2	1.3	2.2	2.2	1.7	T	1.0	T	0.5
Apatite	1.2	1.3	2.2	0.6	1.3	1.5	1.3	T	1.4
Topaz	T	0.6	0.8	1.0	0.7	T		2.2	0.8
Chlorite	4.3	3.5	1.9	2.9	3.3	0.6	1.0	1.9	1.2
Chloritoid			T		T			T	T
Monazite	0.9	1.3	2.2	2.2	1.6	T		T	T
Zoisite	2.2	1.3	2.2	1.6	1.8				
Biotite		0.6	3.0	0.6	1.1	4.2	1.6	1.6	2.5
Kyanite	T		1.4	1.3	0.8				
Others	T	T	0.7	1.5	0.7	5.1	0.9	1.0	2.3
Unidentified	2.3	1.6	0.8	3.2	2.4	1.2	2.3	2.2	1.9
OPAQUES									
Magnetite	15.2	20.9	10.1	11.4	14.4	21.1	13.2	26.4	20.2
Hematite	3.1	5.1	3.5	2.8	3.6	33.4	29.4	15.0	25.9
Limonite	4.3	1.9	6.3	3.5	4.0	7.6	6.1	5.2	6.3
Leucoxene	11.4	10.0	13.7	18.5	12.4	3.6	5.5	5.4	4.8
Altered	14.5	17.1	24.1	14.7	17.6	10.0	19.7	16.0	15.0

T - means trace; other values are percentages.

TABLE 5.

HEAVY MINERALS OF THE EDMONTON SECTIONS.

Sample No:	S12-A	S12-B	S12-C	S12-D	S12-E	S12-F	S12-G	S12-H	S12-J	S12-K	Av.	S13-C	S5-A
Mineral:													
Garnet	15.5	12.3	12.5	13.5	16.2	11.9	13.8	14.8	16.8	17.5	14.5	11.3	16.0
Epidote	11.9	11.8	5.3	11.3	19.2	8.5	11.3	15.1	12.1	9.0	11.6	11.8	5.3
Hornblende	3.3	5.0	0.8	2.9	3.5	1.6	1.0	2.6	2.1	1.5	2.4	2.3	1.8
Titanite	5.1	3.0	2.7	2.4	4.1	2.3	1.8	3.2	3.7	2.0	3.0	2.6	1.5
Zircon	T	1.0	3.5	2.6	1.2	3.1	2.8	1.9	3.2	3.4	2.3		3.5
Tourmaline	0.9	T	1.1	1.2	2.6	1.3	0.8	1.3	0.8	0.5	1.1	1.0	0.6
Rutile	2.7	2.1	0.8	2.6	2.6	2.1	1.0	1.3	1.6	0.5	1.7	0.5	2.3
Staurolite	1.8	3.5	1.1	2.6	5.2	2.6	1.3	1.3	1.6	2.0	2.3	1.0	1.2
Apatite	T	T	2.7			2.3	3.6	T	2.1		2.1	2.3	2.3
Topaz	2.4	0.6	0.5	0.7			3.6	0.8		T	0.9	3.1	1.2
Chlorite	3.6	1.5	0.5	0.5	0.9	3.9	2.0	1.9	1.3	0.5	1.7	0.5	1.5
Chloritoid	0.6	0.9	0.5	1.4	1.5	T	0.5	0.8		1.0	0.8	1.0	0.6
Monazite	3.0	1.5	T	2.2	2.3	1.3	1.5	0.8	1.6	1.2	1.6	1.3	T
Zoisite	1.5	0.9				T		T	0.5	T	0.5	1.3	1.2
Biotite	0.9	1.5	0.8		T	2.8		T		0.5	0.7	3.1	0.6
Kyanite	1.2			T	T	0.5		T	0.5		0.3		
Others	T		0.6	T		T	3.6	1.9		T	0.7	1.0	
Unidentified	2.4	1.4	1.3	1.2	1.7	1.0	1.3	1.6	1.1	2.0	1.5	2.8	0.6
OPAQUES													
Magnetite	13.1	20.0	45.8	25.5	12.0	20.0	28.0	21.4	28.1	46.8	26.1	8.7	49.3
Hematite	3.6	4.2	10.9	8.2	6.4	14.7	5.9	5.0	7.4	1.7	6.8	15.2	4.4
Limonite	5.7	7.1	3.2	6.0	7.0	9.3	4.6	4.2	5.0	2.2	5.4	9.0	3.5
Leucoxene	4.5	3.9	0.8	4.3	3.3	2.6	2.0	6.9	4.2	1.7	3.4	5.1	4.1
Altered	15.2	18.6	5.1	10.0	9.6	7.2	9.5	12.4	6.6	5.4	10.0	14.9	4.4

T - means trace; other values are percentages.

TABLE 6.

HEAVY MINERALS OF THE TERTIARY BEDS

Sample:	P1	H1
Mineral		
Garnet	7.4	9.9
Epidote	7.2	6.8
Hornblende	9.0	8.8
Titanite	T	1.0
Zircon	0.8	1.0
Tourmaline	T	0.5
Rutile	1.5	1.6
Staurolite	2.3	1.0
Apatite	1.3	
Topaz	T	
Chlorite	5.9	1.3
Chloritoid		1.8
Monazite	T	T
Zoisite	2.0	1.0
Biotite	3.8	
Kyanite		1.0
Pyroxene		0.5
Carbonates	3.3	
Others	0.5	0.6
Unidentified	2.6	2.1
OPAQUES		
Magnetite	6.7	31.7
Hematite	4.6	3.9
Limonite	5.4	7.0
Leucoxene	2.0	5.2
Altered	32.5	13.0
Gold	T	

T - means trace; other values are percentages.

TABLE 7.

AVERAGE HEAVY MINERAL PERCENTAGES FOR DIFFERENT SECTIONS

Section:	S2	S3	S7	S10	S12	P1	H1
Mineral							
Garnet	12.5	12.2	14.0	5.0	14.5	7.4	9.9
Epidote	7.6	5.5	7.6	3.8	11.6	7.2	6.8
Hornblende	2.9	5.3	2.9	3.4	2.4	9.0	8.8
Titanite	0.8	2.8	1.1	0.7	3.0	T	1.0
Zircon	1.4	1.3	1.2	1.2	2.3	0.8	1.0
Tourmaline	0.9	0.6	1.0	1.1	1.1	T	0.5
Rutile	2.0	2.3	2.1	0.7	1.7	1.5	1.6
Staurolite	2.6	2.6	1.7	0.5	2.3	2.3	1.0
Apatite	2.1	2.8	1.3	1.4	2.1	1.3	
Topaz	0.6	0.5	0.7	0.8	0.9	T	
Chlorite	1.6	1.5	3.3	1.2	1.7	5.9	1.3
Chloritoid	0.4	1.0	T	T	0.8		1.8
Monazite	0.7	1.3	1.6	T	1.6	T	T
Zoisite	1.4	1.0	1.8		0.5	2.0	1.0
Biotite	0.9	4.0	1.1	2.5	0.7	3.8	
Kyanite	0.4	T	0.8		0.3		1.0
Others	0.7		0.7	2.3	0.7	0.5	0.6
Unidentified	2.3	2.2	2.4	1.9	1.5	2.6	2.1
OPAQUES							
Magnetite	26.4	24.5	14.4	20.2	26.1	6.7	31.7
Hematite	4.9	6.2	3.6	25.9	6.3	4.6	3.9
Limonite	11.8	6.7	4.0	6.3	5.4	5.4	7.0
Leucoxene	3.9	2.1	12.4	4.8	3.4	2.0	5.2
Altered	11.4	15.4	17.6	15.2	10.0	32.5	13.0

T - means trace; other values are percentages.

Light Mineral Analyses:

The light mineral fraction was not studied with the same detail as the heavy mineral fraction. Rather, an examination of a few light mineral slides from each section was made. Clear angular quartz was found to be the dominant mineral, forming up to 90% of the total light minerals. The majority of the quartz showed good extinction, though grains showing undulating extinction were noted. Chlorite, having a dirty yellow to green color, was present in small quantities, usually less than 1%.

Carbonate grains, mainly calcite, were found in all the sections of the Saskatchewan sands. A rough count showed the carbonates to be most common in the Lethbridge section and least common in the Edmonton section. These results agree with the insoluble residue tests. The carbonate grains were rounded and fractured along cleavage planes which indicates their detrital nature.

Feldspars formed an estimated 3% of the light mineral assemblage in the Saskatchewan sands. In the Paskapoo sandstone the value rose to about 6% of the total mineral suite. Definite identification of many grains was difficult as the birefringence and relief are close to that of quartz and cleavage and elongation are often indistinct. Identification was made on the basis of polysynthetic twinning, and an occasional good

biaxial figure. Alteration was noted where cleavage cracks were discernable.

Interpretations of Mineral Analyses:

From an analysis of the mineral types, their abundance and alteration, the following facts are apparent:

(1) Only the 120 to 230 mesh material was analysed. It is probable that the heavy mineral content is greater for this size than for the average. Smithson (1939, p. 356), observed that the average size of the grains decreased with increase in density of the minerals. As the size here analysed is less than the median sand size for the samples, in all probability the concentrations of heavy minerals is greater within this range than in the average sand content. This is not altogether unfavorable, to determine the heavy minerals present the size showing their greatest abundance should be used. Some minerals may decrease in amount in the large sizes so that their presence would not be noted.

(2) The average percentages of the heavy minerals in the different sections were found to be about the same even though individual samples varied to a greater extent. Thus by examining numerous samples from different horizons of a section very local depositional conditions were eliminated.

(3) Concentrations of magnetite are noted in some samples. Generally, when this high magnetite content was present, a higher percentage of zircon was also noted even

though the total number of transparent minerals counted decreased. This anomaly is produced by local variation in currents giving placer type deposits.

(4) The Hand Hills conglomerate, Basal Paskapoo sandstone and Saskatchewan sands all have similar heavy mineral assemblages. This would serve to indicate that they have been derived from the same source.

(5) Hornblende was found to be equally distributed throughout the sections. Alteration of the hornblende is present, however this alteration is equally present throughout the section and no notable increase is present going up in Saskatchewan sand sections. This lack of surface alteration indicates either quick burial after deposition or erosion of the weathered zone. At no section was there any field evidence of a weathered zone observed, yet the Saskatchewan sands and gravels do not appear to be disturbed. These facts suggest that the Saskatchewan sands and gravels are immediately preglacial in regard to time of deposition.

(6) A source directly from the mountains of the west is indicated by the presence of unstables. It is doubtful that feldspar could remain after a reworking of an older sediment of the area. The presence of carbonates, with an increase as the mountains are approached, suggests a primary source from the mountains. Possible sources of the feldspar are the Precambrian arkoses of the Rocky Mountains, granitic terrain west of the continen-

tal divide, or perhaps Tertiary rocks of the plains. Carbonates were doubtlessly derived from the limestone beds of the Rocky Mountains.

(7) Garnet formed higher percentages in the northern sections than at Lethbridge. However, the higher percentages of the ferric oxides and hydroxides at Lethbridge may have a masking effect. It is noteworthy that the dominant garnet variety at Lethbridge is a yellow-brown to brown variety and in the northern sections, a clear variety is dominant. Crystalline schists and gneisses are regarded as the dominant source beds of garnets. There is a lack of these beds east of the continental divide, thus the origin of the garnets is probably from metamorphic rocks west of the Rocky Mountain trench.

(8) Kyanite, though never abundant, is present in the northern sections of the Saskatchewan sands but altogether lacking in the Lethbridge section. This may indicate that streams depositing the northern material may have had access to the kyanite deposits present near the north portion of the Big Bend Highway of British Columbia. There is also a presence of other metamorphic minerals, eg., garnet, epidote, green hornblende, tourmaline, staurolite, zoisite, which indicate a source for the Saskatchewan sands in the metamorphic series west of the Rocky Mountain trench.

In general, the angularity of the grains, presence of

unstable minerals and a large variety of metamorphic minerals present indicate a primary origin for the Saskatchewan sands with at least a partial source in the metamorphic series west of the Rocky Mountain Trench.

CHAPTER IV

CONCLUSIONS

Taking into account the general Tertiary Geologic history of Alberta, there are three possible sources for the Saskatchewan Sands and Gravels; first, pre-existing Tertiary beds, second, the Rocky Mountains east of the present continental divide, and third, the mountains west of the present divide carrying metamorphic rocks. The relative merits of each possible source will be discussed.

(1) Pre-existing Tertiary beds.

Under this group are included the gravels of the Cypress and Flaxville Plains, remnants of which are seen at present covering the Cypress, Hand and Swan Hills, and the Paskapoo sandstone which outcrops as a ridge near Olds, Alberta, and shows surface expression north and south from there. Writers in the past (McConnell (1885), Tyrrell (1890), Calhoun (1906), Williams and Dyer (1930) and Rutherford (1937)) have considered these Tertiary beds as at least a partial source for the Saskatchewan sands and gravels. The mineral analyses, however, indicate a similar source rather than a derivation of the Saskatchewan sands and gravels from these Tertiary beds. It is doubtful that unstable minerals could have withstood the weathering present in a reworking of these beds. Also an increase in carbonates with approach to the west and the presence of Saskatchewan sands and gravels well within the foothills indicate a primary origin from the mountains.

High relief is necessary to get aggradation of 70-80 feet of sands in rivers on the plains. If these high areas had been removed prior to glaciation a deep weathering zone should be found. It is also doubtful that glacial action could have destroyed this high relief since glaciers appeared to have little effect on the Swan, Hand and Cypress Hills.

In conclusion, perhaps some of the pebble portions of these Tertiary conglomerates, which remained as lag deposits, could have formed gravels but it is doubtful that the sand portion was so derived. Pettijohn (1949, p. 429) says pebbles reflect local character whereas the sands are indicative of the source beds of the headwater area.

(2) Rocky Mountains east of the present divide.

Much of the material doubtless was derived from the Eastern Rockies. However, could this area also have been the source of the metamorphics recognized? It is very doubtful that metamorphism of Rocky Mountain beds has proceeded far enough to produce these minerals. This is especially true in the southern section where no known metamorphics are found east of the divide. This could be checked by collecting samples of the material eroded by the present streams within the mountains, for example, the Miette River at Jasper, and the head waters of the Athabaska River, here though there is a risk of contamination due to glaciation.

(3) Mountains west of the divide containing the metamorphic series.

Metamorphic horizons are known west of the divide and these could provide a source for the metamorphic minerals found in the Saskatchewan sands and gravels.

The Basal Paskapoo sandstone, Hand Hills conglomerate, and Saskatchewan sands and gravels appear to have a similar source. The Paskapoo sandstone is Paleocene. At this time the Rocky Mountains had just started to form and the Selkirk Mountain area was probably higher at the time and rivers originating in the Selkirk Mountains could drain eastward. These east flowing streams could cut down as fast as the Rocky Mountains rose. This condition may have existed during deposition of the Hand Hills conglomerate through to the deposition of the Saskatchewan sands and gravels. Following this, the faster eroding streams flowing to the west (because of the steeper gradient) may have captured the head waters of the old eastward flowing streams, forming the present divide.

Yellowhead Pass was the only pass seen by the author. This is a remarkably low pass with respect to the present main streams. It does not seem inconceivable that this may have been the old valley of an antecedent stream.

Writers in the past, eg. Alden (1924, 1932), Allan and Rutherford (1934), have postulated uplift during Pleistocene time within the Rocky Mountain chain. Thus capture by the Pacific streams eg. Columbia and Fraser Rivers, plus latest uplift may have set the present divide.

The age of the Saskatchewan sands and gravels cannot be definitely answered. However, the lack of a weathering zone indicates a period of deposition just prior to glaciation of the area.

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Plates I-III: Photographs taken in the field showing Saskatchewan sands and gravels sections.

Plates IV-VI: Photomicrographs showing individual grains of heavy minerals.

See Page 7 for section numbers.

PLATE I

Section at Lethbridge, Alberta, showing the relief on the Cretaceous bedrock.

Section at Lethbridge, Alberta, (S10) showing the sand channels at the top of the Saskatchewan gravels.


Basal Till
Sask gr
Cret sh

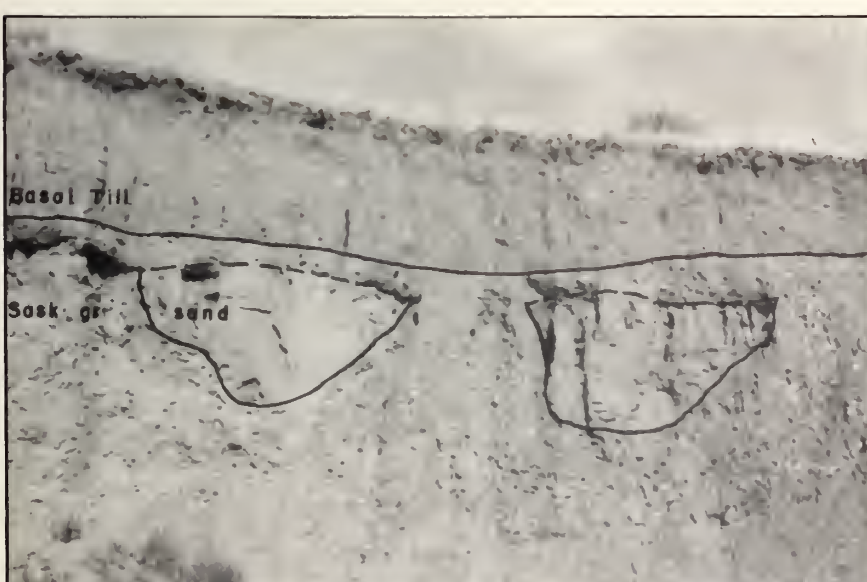
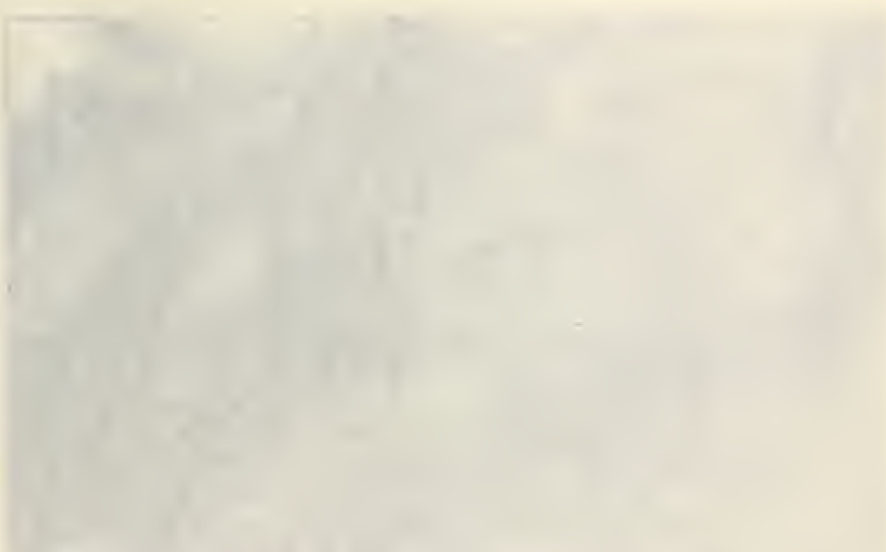

Basal Till
Sask gr
sand

PLATE II

Big Bend section, Edmonton area, showing the springs coming out of the bank at the base of the Saskatchewan sands and gravels.



Crossbedding shown in the Saskatchewan sands of the Big Bend section, Edmonton, Alberta.

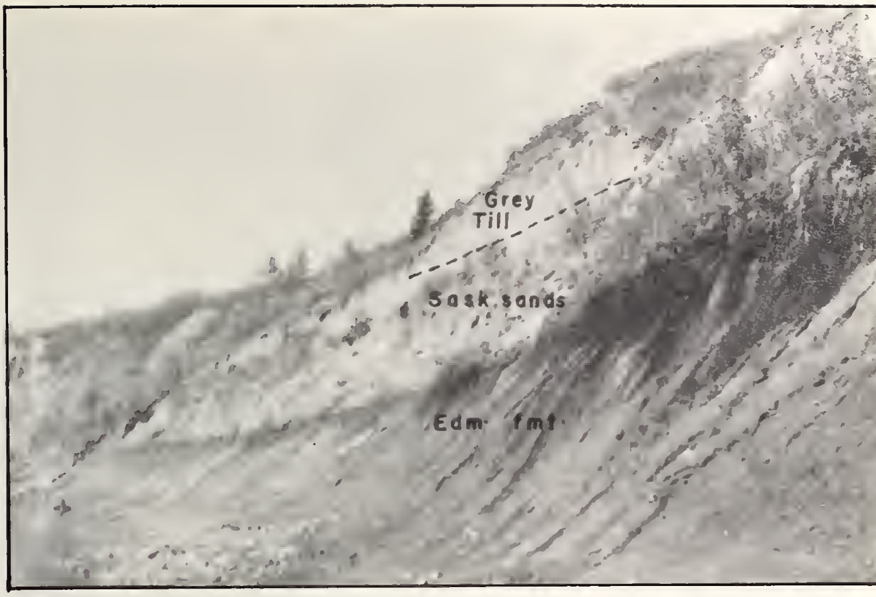

Grey
Till
Sask.sands
Edm fmt

PLATE III

The Basal Paskapoo sandstone outcropping along the Pembina River just above Highway No. 16 crossing.

The section as seen in the abandoned Blue Flame Coal Pit on the north shore of Lake Wabamun.

PLATE IV.

Magnification: X145.

Hornblende; P1
showing angularity
and inclusions.

Hornblende: S10-A
showing hole due
to alteration.

Hornblende: S12-D
showing cleavage and
incipient alteration.

Hornblende: P1
showing jagged edges.
(cockscomb structure?)

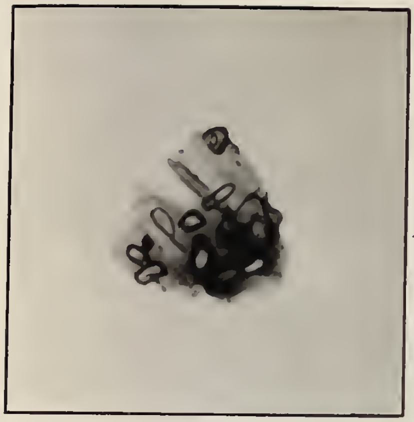
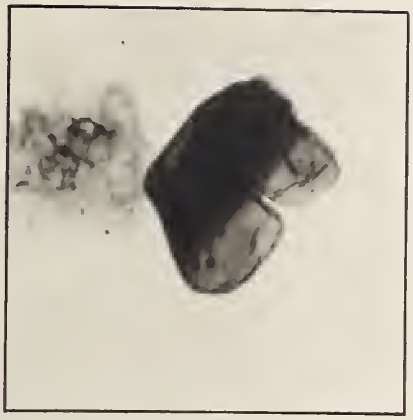
Hornblende: S12-A
showing inclusions

Garnet: S12-A
showing dodecahedral
form.

Garnet: S10-A.
Yellow-brown
variety from
Lethbridge.

Garnet: S12-D.
showing pitted
surface.

Garnet: S12-A.
showing inclusions
and conchoidal
fracture.





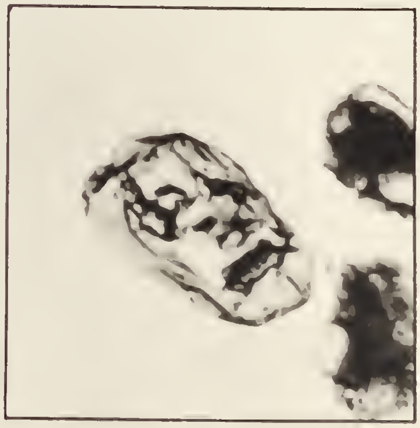



PLATE V.

Magnification: X145.

Hornblende: P1 showing angular grain.

Gold: Panning. Under reflected light and crossed nicols.

Chloritoid: S12-D.

Staurolite: S12-H

Kyanite: S3-A. Showing angular grain.

Epidote: S12-K;

Epidote: S12-A

Epidote: S12-A

Epidote: S10-C.

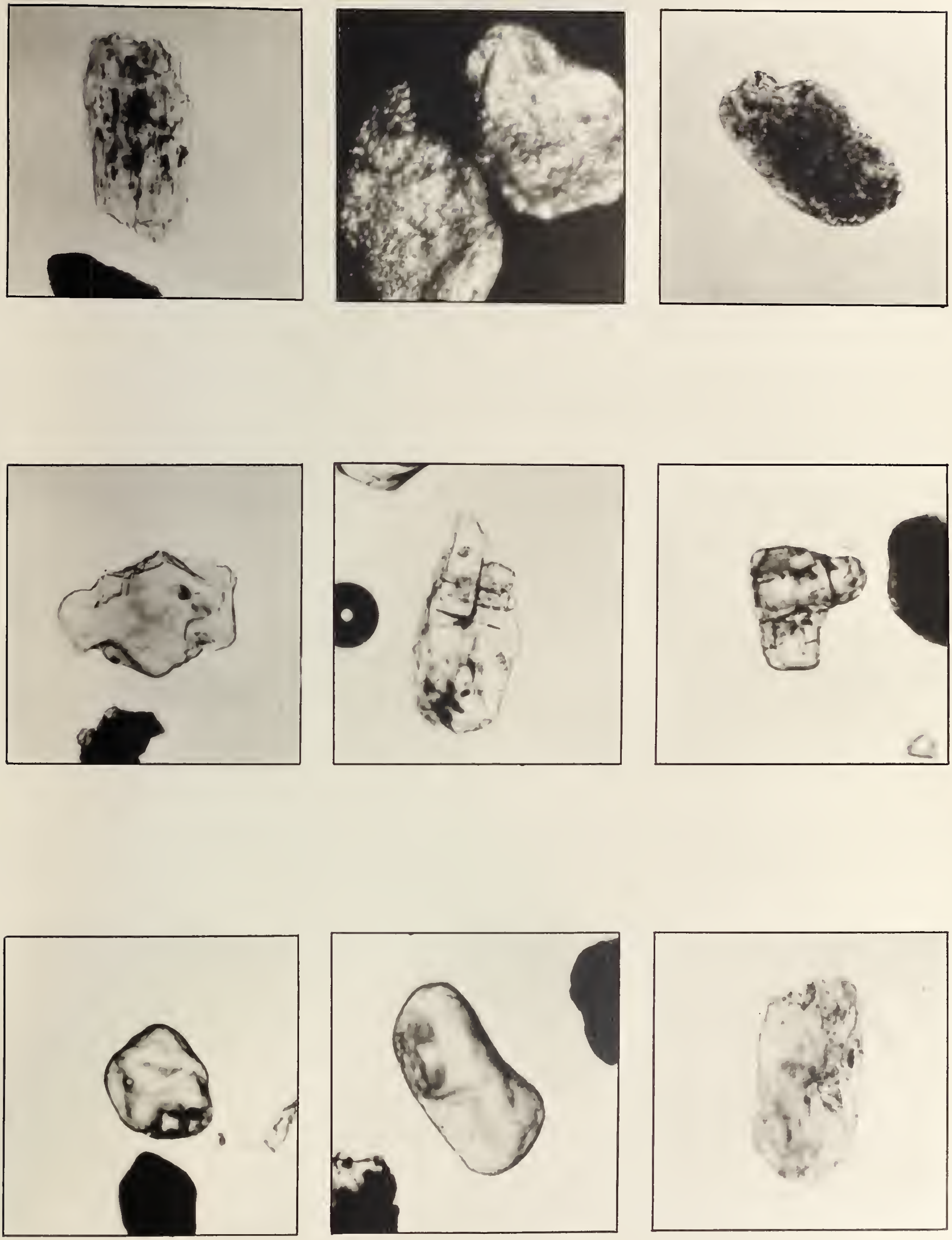


PLATE VI.

Magnification: X145.

Zircon: From panning tailings. Showing euhedral form.

Zircon and Garnet. S10-C.

Zircon: From panning tailings. Showing euhedral form.

Titanite: S12-A

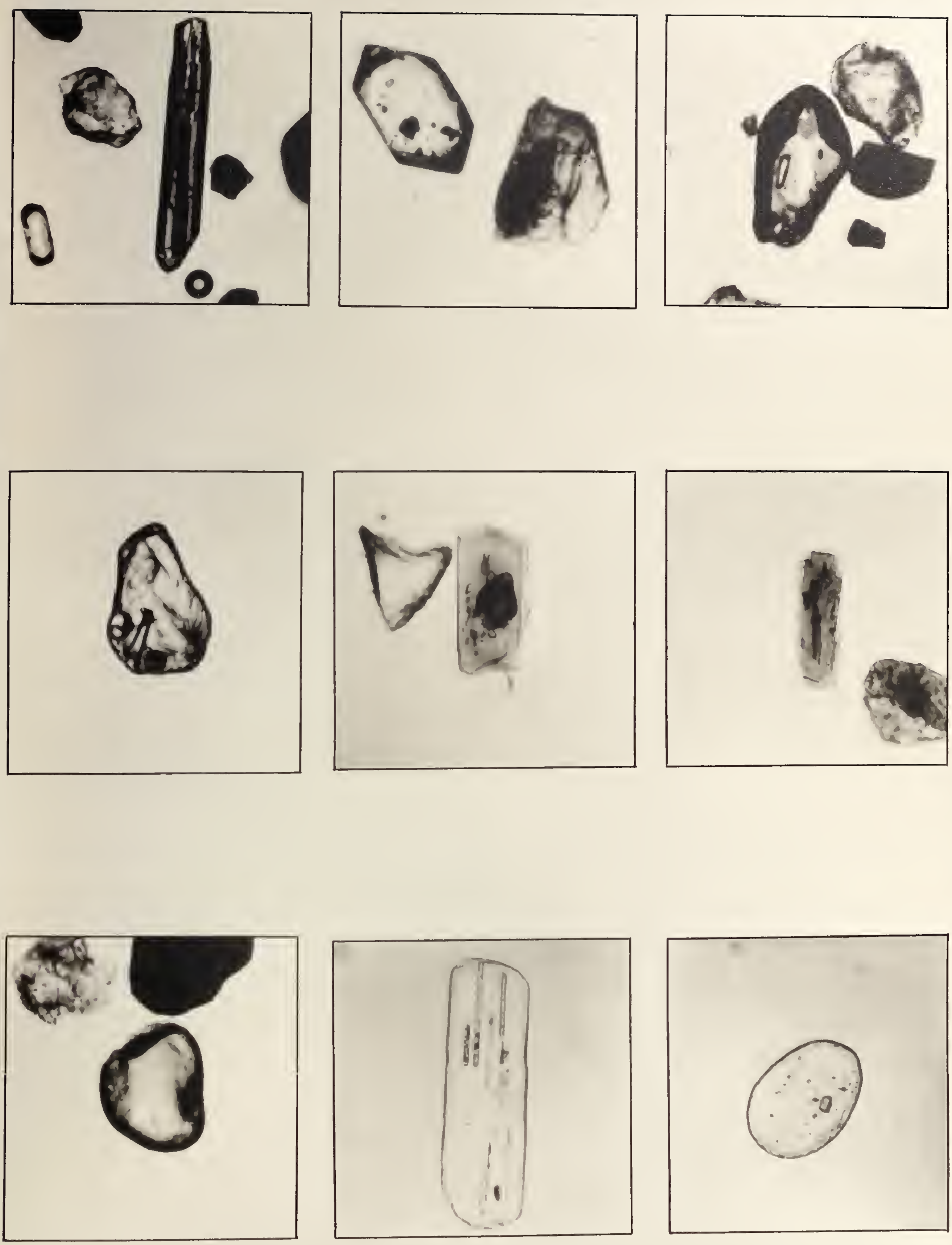
Tourmaline: S10-C. Showing inclusions.

Tourmaline: S12-D

Rutile: S10-C. Well rounded, probably secondary.

Apatite: S12-J. Showing aligned inclusions.

Apatite: S12-J. Showing rounded character.



APPENDIX

DESCRIPTION OF SECTIONS

LETHBRIDGE SECTION: (much of description taken from Horberg (1952)).

Thickness	Total Depth Below Surface	Bed
		Upper Till
40'	40'	- grey-brown, calcareous; lower 20 feet unoxidized; rude layering and silt inclusions in lower part; local sand at base.
		Lenzie Silt
60'	100'	- mainly a buff to tan silt; top 8 feet is varved with 3-18 inch beds below this some sand layers and pebbles present. Majority of the section is composed of indistinct bedded and cross-bedded silts with a possibility of some wind deposits. Near the bottom a 3 foot black clay bed is present. This is underlain by a 5 foot calcareous, grey-tan sand bed.
		Lower Till
36'	136'	- dark grey; upper 20' is oxidized to a brown grey; has a crumbly break; (see Frontispiece).
		Basal Till
5'	141'	- dark grey; topped by a 2 inch rusty weathering zone; compact and cliff forming showing a columnar jointing.
		Saskatchewan Sands and Gravels
0-4' (S10-A)	145'	- sand channels present at the top of the Saskatchewan gravels. Sands are a light olive grey; cross-bedding is distinct (see plate I).
16-20' (S10-B) (S10-C)	161'	- gravels with sand filling interstices. The gravels are well rounded, dominantly quartzite and cherts. Bedding is indistinct; Upper contact is fairly regular; lower contact is irregular and relief present on bedrock (see Plate I).
		Cretaceous Bedrock
30'	191'	- Bedrock formed by the Bearpaw shale, a black carbonaceous shale.

RED DEER SECTION:

Thickness	Total Depth below surface	Bed
		<u>Brown Till</u>
15'	15'	-pale to moderate brown till; upper 5 feet clearly weathered; boulders common often up to 8 inches in diameter. The brown till is compact, forming vertical cliffs. Thickness is variable
		<u>Water Laid Sand</u>
0-1'	16'	-lens of water laid sand between the Brown and Grey tills. This sand is discontinuous.
		<u>Grey Till</u>
10'	26'	-olive grey till. Thickness is variable. Boulders are present but not common. Till exhibits a crumbly appearance.
		<u>Saskatchewan Sands and Gravels</u>
0-1' (S7-B)	27'	-sand lens; present only in depressions in the gravels below.
7' (S7-C)	34'	-poorly sorted gravels with some pebbles 5 inches in diameter; contains interstitial sand; bedding indistinct.
1' (S7-D)	35'	-gravel bed containing pebbbles 0.5 to 1 inch in diameter and usually disk shaped. Noted are a lack of any interstitial sand and a distinctive rusty weathered coating on the pebbles.
8' (S7-E)	43'	-poorly sorted gravels with interstitial sand; bedding indistinct.
1' (S7-F)	44'	-bed containing gravels as above but interstitial material is predominantly clay from the shales below.
		<u>Bedrock</u>
		Bedrock formed by shales of the Edmonton formation.

LAKE WABAMUN (Blue Flame Coal Pit)

Thickness	Total Depth below surface	Bed
		<u>Brown Till</u>
6'	6'	-grey-brown till containing pebbles up to 6 inches diameter. Top 3 feet weathered; crumbly character evident. The till is disseminated with a white alkaline material.
		<u>Saskatchewan Sands and Gravels</u>
6' (S2-A)	12'	-buff-grey, water laid sand showing a distinct crossbedding. Several discontinuous 2 inch gravel beds were noted in the sand.

LAKE WABAMUN (Blue Flame Coal Pit)

Thickness		Total Depth Below Surface	Bed
7'	(S2-B)	19'	-poorly sorted gravels composed dominantly of a light colored quartzite and containing interstitial sands; bedding indistinct.
0-3'	(S2-C)	22'	-buff-brown sand with bedding indistinct; numerous coal and shale fragments present. A higher percentage of black chert noted here than in S2-A.
			Bedrock
20'		42'	Bedrock formed by Edmonton shales and coal seams.

LAKE WABAMUN (Victory Strip Mine)

Thickness		Total Depth Below Surface	Bed
			Top beds removed by stripping operations.
			Saskatchewan Sands and Gravels
8'		8'	-bed of gravel, dominantly light coloured quartzite and interstitial sand. The bed is leached giving a light grey color to the sands.
15'	(S3-A)	23'	-poorly sorted gravels with interstitial sand. No leaching is evident.
18'	(S3-B)	41'	-light yellow brown sand. Bedding and crossbedding present but not distinct.
			Bedrock
8'		49'	Bedrock composed of Edmonton shales and coal.

EDMONTON (Big Bend Section).

Thickness	Total Depth Below Surface	Bed
20'	20'	-covered area.
		Water Laid Silt
8'	28'	-stratified silt of a moderate yellow-brown colour. Lower contact is irregular, upper contact covered. Underlain by an 8 inch rusty-weathered zone
		Brown Till
25'	53'	-grey-brown till with numerous boulders, often up to 8 inches in diameter. A competent member forming vertical cliffs and exhibiting columnar jointing.
		Grey Till
10'	63'	-light olive grey till lying below the Brown Till and grading into it so that contact difficult to recognize. Characterized by crumbly appearance and a scarcity of pebbles and boulders.

EDMONTON (Big Bend Section)

Thickness		Total Depth Below Surface	Bed
			Saskatchewan Sands and Gravels
1'		64'	-transitional bed containing alternating clay and sand bands. Sand bands rusty weathered; carbonous fragments numerous.
1.5'	(S12-A)	65.5'	-distinct crossbedded, yellowish brown sand; no carbonaceous material or pebbles noted.
1.5'		67'	-strongly crossbedded sand containing pebbles and much carbonaceous material.
4'	(S12-B)	71'	-fine-grained yellowish-brown sand. Bed stands up better to erosion than rest of sand suggesting clay content.
8'	(S12-C)	79'	-medium grained, crossbedded sand containing carbonaceous fragments.
10'	(S12-D)	89'	-as above but exhibiting extreme crossbedding.
10'	(S12-E)	99'	-as above; crossbedding less evident.
10'	(S12-F)	109'	-as above.
10'	(S12-G)	119'	-as above.
2'		121'	-sand containing ironstone pebbles and armored mud balls.
8'	(S12-H)	129'	-medium grained, crossbedded, yellow brown sand.
6'		135'	-sand as above.
0.5'		135.5'	-iron oxide band present as a rusty colored zone. The iron oxide coats the sand grains. The band persists about 2.5' above a gravel bed and crosses the bedding.
2.5'	(S12-J)	138'	-sand as above the iron oxide band.
2.3'	(S12-K)	140'	-gravel bed containing ironstone and well-rounded qtzt. pebbles. Interstitial material composed of sand and clay from shales below. This bed is marked by seepage of water (see Plate II).
			Bedrock
30'		170'	Bedrock composed of shales of the Edmonton formation.

EDMONTON (Groat Ravine Section)

Thickness	Total Depth Below Surface	Bed
		Covered.
		Grey Till
8'	8'	-olive grey till showing few boulders; carbonaceous material present.

EDMONTON (Groat Ravine Section)

Thickness	Total Depth Below Surface	Bed
		Saskatchewan Sands and Gravels
3'	11'	-transition bed of mixed sand and clay.
6' (S13-A)	17'	-yellowish-brown crossbedded sand; some carbonaceous material present.
0.2' (S13-B)	17'	-indurated sand (suggestion of cement); resistant to erosion.
5' (S13-C)	22'	-yellowish-brown sand containing a few 1 inch clay bands.
10' (S13-D)	32'	-sand as above, no clay bands noted.
10' (S13-E)	42'	-sand as above
5' (S13-F)	47'	-sand as above.
		Base of exposure but not base of the Saskatchewan sands and gravels.